AN4411
Application note

ST7580 802.15.4-like MAC layer

By Nunzio Dipaola

Introduction

The new smart-grid systems and the emerging “Internet of things” concept require advanced web services based on the TCP/IPv6 communication protocol. The TCP/IPv6 stack has been adapted to narrow band communication systems thanks to the work of the 6LowPAN working group of the IETF for narrow band wireless PANs, based on the IEEE-802.15.4 compliant MAC layer.

The same concept can extended to narrow band wired power line communication networks by implementing an 802.15.4-like MAC layer on a 32-bit microcontroller of the STM32 family, on top of the ST7580 multi mode power line networking SoC. The ST7580 device inside the STarGRID family offers sufficient flexibility to support such protocol and even the STM32F103 MCU has been used for the first firmware release; it can be ported to other devices in the STM32 family.

This document describes the communication protocol and the services provided to the upper layers of the protocol stack.

Contents

List of figures

1 Overview

The 802.15.4-like communication MAC layer provides services able to build and manage a power line network with a master node referred to as “network coordinator” and several peer nodes called “coordinators”.

Any type of power line network may be created.

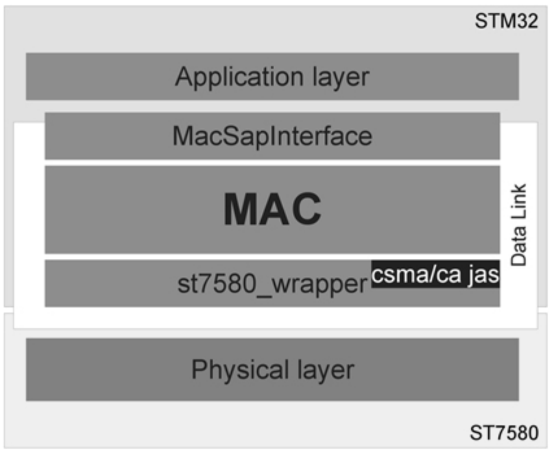
In order to start transmissions, a coordinator node needs to join the network; it performs an association procedure called “active scan”.

The protocol has been created for the STM32 family microcontrollers. It assumes a serial communication line (UART) is used to communicate and exchange data with the ST7580 power line modem device.

2 Firmware architecture

Figure 1 shows the firmware architecture:

Figure 1. Firmware architecture



The ST7580 power line modem provides physical layer services together with some basic data link layer services. The role of each block is as follows:

- **st7580_wrapper**: this module works as a wrapper for any access to the modem. When transmitting, this module sends frames to the modem and manages the local port acknowledgments (UART communication). When receiving, this module analyzes the packet and sends the related event to the right FSM among the MAC machines. The outgoing packets are evaluated by the CSMA/CA JAS anti-collision module in order to obey the medium access protocol rules; the only exceptions are ACK packets and all the segments of a series, excluding the first.
- **MAC**: this is a set of modules which provides all the functionality of the data link layer. Here, several FSMs work together to execute requests issued from the higher layer and manage the data gathered by the modem from the power line (such as other nodes in the network in a neighbor table, the quality level of the medium and internal data structures).
- **MacSapInterface**: this module provides a unique, clean interface to the whole set of MAC services including request, confirmation and indication primitives. This modules is the interface for the application layer which is built upon the power line network device.

Table 1 shows the source files involved in any block.

Table 1. Module details

Block	Modules	Notes
st7580_wrapper	ST7580_Layer\st7580_wrapper (c/h) ST7580_Layer\st7580_serial20 (c/h) BSP\STM32_EVAL\st7580_stm32_bsp (c/h)	Very low-level modules.

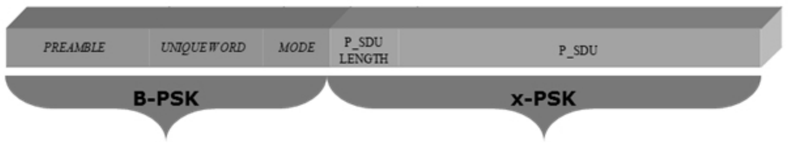
Table 1. Module details

MAC	MAC\MacConstants.h MAC\MacEnumeration.h MAC\MacFrameCreation/Handling (c/h) MAC\MacFSM* (c/h) MAC\MacMessageCatalog.h MAC\MacNeighbourTable (c/h) MAC\MacPanDescriptorMng (c/h) MAC\MacPibAttributes (c/h) MAC\MacPIBTypes.h MAC\MacSapQueue (c/h) DataLinkLayer\channel_access (c/h) DataLinkLayer\csmaca (c/h) DataLinkLayer\timers (c/h)	The source files in DataLinkLayer\subfolder are dedicated to the CSMA/CA JAS access protocol; this can be enabled at build time by declaring a special macro ENABLE_CSMA_CA (default). If this macro is not declared, no access protocol is used.
MacSapInterface	MAC\MacSapInterface (c/h)	Applications may be built using the API these modules provide.

3 Framing

The adopted modulation is an X-PSK and the physical frame is the typical PSK frame, shown in *Figure 2*.

Figure 2. PSK frame

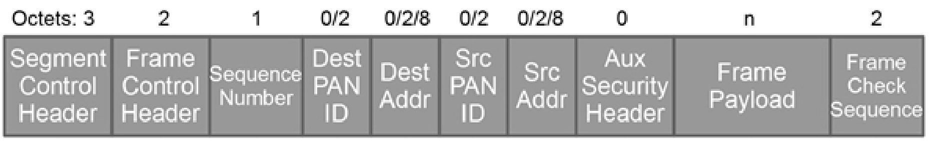


Where:

- Preamble: 32 bit (this field is detected as start-of-frame signal by the receiver)
- Unique word: 32 bit (fixed content - the receiver evaluates SNR of the medium depending on the perceived quality of this field)
- Mode: 8 bit (this field specifies the modulation scheme for the incoming payload – in this protocol version, it is always set to B-PSK)
- P_SDU Length: 8 bit (length of the P_SDU field in bytes)
- P_SDU: variable field, from 0 up to 248 bytes (this is the actual frame payload)

The P_SDU field contains the MAC PDU with the structure shown in figure 3.

Figure 3. Fields of the MAC frame



Octets: 3	2	1	0/2	0/2/8	0/2	0/2/8	0	n	2
Segment Control Header	Frame Control Header	Sequence Number	Dest PAN ID	Dest Addr	Src PAN ID	Src Addr	Aux Security Header	Frame Payload	Frame Check Sequence

The content of each field is detailed below.

Segment control header

This field stores useful data for segmentation and reassembly routines (*Table 2*).

Table 2. Fields of the segment control header

Field	Byte	Used bits	Bit length	Details
RES	0	7-2	6	Reserved
CAP	0	1	1	Channel Access Priority (1: high, 0: normal)
LSF	0	0	1	Last Segment Flag (1: yes, 0: no)
SC	1	7-2	6	Segment Count
SL[9-8]	1	1-0	2	Segment Length
SL[7-0]	2	7-0	8	Segment Length

Note that the SL field stores the length of a generic segment in a series, not the actual segment. Therefore, when sending a 140 byte packet, while the actual segment size is 60 bytes, this field is set to 60 in segment #1, then 60 in segment #2 and 60 again in segment #3, even if this last segment only holds the last 20 bytes.

Frame control header

This field is used for specifying the frame type and the addressing modes (table 5).

.

Table 3. Frame control header

Field	Byte	Used bits	Bit length	Details
Frame type	0	0-2	3	Frame type (see notes)
Security enabled	0	3	1	Always zero
Frame pending	0	4	1	Always zero
Ack request	0	5	1	Acknowledgment requested
PAN ID compression	0	6	1	Enabled/disabled (see notes)
Reserved	0, 1	7, 0-1	3	
Dest. addr. mode	1	2-3	2	Addressing mode (see notes)
Frame version	1	4-5	2	Always zero
Source addr. mode	1	6-7	2	Addressing mode (see notes)

The “frame type” field is set to one of the allowed values:

- 000 = Beacon
- 001 = Data frame
- 010 = Acknowledgment
- 011 = MAC Command frame
- 100-111 are reserved

The “PAN ID compression” field saves (in some cases) two bytes: when both the source address and the destination address are present and the source PAN ID is identical to the destination PAN ID, then this field may be set to one (enabled) and only the destination PAN ID is copied into the frame (source address doesn’t have an explicit PAN ID). In any other case, this field is set to zero.

The “addressing mode” fields may be set to one of the allowed values:

- 00 = address field is not present (that is, no address)
- 01 is reserved
- 10 = address field contains PAN ID and a 16 bit short address
- 11 = address field contains PAN ID and a 64 bit extended address

Sequence number

This field is under the MAC control. It specifies the sequence number of the frame, which is useful for matching acknowledgments and distinguishing between subsequent retransmissions. A BSN (beacon sequence number) is used for beacon frames and a DSN (data sequence number) is used for data frames.

Frame payload

This field is used for the MAC payload. Different frames are associated with different cases:

- Beacon frame: the payload is 16-bits long and can be set to one of the following two values:
  - MAC_BEACON_SUPERFRAME_PANCOORD (the sender node is a network coordinator and association is allowed);
  - MAC_BEACON_SUPERFRAME_COORD (the sender node is a coordinator and association is allowed);
- MAC Command frame: the command itself is 8 bits long and the payload may vary. Two different command frames are available:
  - MAC_BEACON_REQ_ID (Beacon Request Command Frame – only the command code is specified, no payload);
  - MAC_IDENTITY_ANNOUNCEMENT (Identity Announcement Command Frame – the command code is followed by the 16-bit short address and then by the 64-bit extended address of the node);
- Acknowledgment: no payload;
- Data frame: any payload.

Frame check sequence

Not used. The physical layer of the ST7580 provides hardware error detection, so this field is not filled with any data.

4 Service description

The firmware offers a complete set of service primitives, as listed in *Table 4*.

Table 4. List of service primitives

	request	confirm	indication
MCPS-DATA	yes	yes	yes
MLME-BEACON-NOTIFY			yes
MLME-GET	yes	yes	
MLME-SET	yes	yes	
MLME-RESET	yes	yes	
MLME-SCAN	yes	yes	
MLME-START	yes	yes	
MLME-COMM-STATUS			yes
MLME-SYNC-LOSS			yes

4.1 Address structure

The address of a node is a commonly used data structure, so it is useful to acquire it beforehand.

```
typedef struct {
     uint8_t  Mode;
     uint16_t PanID;
     union {
          uint16_t Short;
uint8_t  Extended[MAC_ADDR64_SIZE];
     };
} MAC_DeviceAddress_t;
```

where:

- uint8_t Mode
  is the address mode (see notes below table 5)
- uint16_t PanID
  is the 16-bit PAN Identifier
- uint16_t Short
  is the 16-bit short address
- uint8_t Extended
  is the 64-bit extended address (the macro MAC_ADDR64_SIZE has value 8)

4.2 Data services

The data services include all the primitives related to data transmission, that is, to MCPS-DATA functions such as “request”, “confirm” and “indication”.

4.2.1 MCPS-DATA.request

```
uint8_t MAC_McpsDataReq(MAC_McpsDataReq_t *McpsDataReq);
```

This function is called when a data transmission is requested. Input data is a reference to a MAC_McpsDataReq_t data structure with the following fields:

- uint8_t SrcAddrMode

The source address mode, as listed in the notes below table 5.

- MAC_DeviceAddress_t DstAddr

The destination address.

- uint16_t MsduLength

The length in bytes of the MSDU. The firmware can handle messages up to NEXT_HIGHER_LAYER_MAX_PDU_LENGTH bytes in length through segmentation. The default value for NEXT_HIGHER_LAYER_MAX_PDU_LENGTH is 1280.

- uint8_t *Msdu
  Pointer to the MSDU.
- uint8_t MsduHandle
  The handle associated with the data to transmit.
- uint8_t TxOptions
  Special transmission options:
  - b0: 0 tx without ACK, 1 tx with ACK
  - b1: 0 CAP transmission (fixed)
  - b2: 0 direct transmission (fixed)
- uint8_t SecurityLevel
  Always zero.
- uint8_t QoS
  Requested Quality of Service: 1 high, 0 normal

Return values:

- MAC_SAP_ERR_NO_ERROR – operation completed successfully;
- MAC_SAP_ERR_IMPLEMENTATION – no spare room in the event queue; other operations are already being performed;
- MAC_SAP_ERR_INVALID_ADDR_MODE – invalid source address mode or destination address mode.

4.2.2 MCPS-DATA.confirm

```
uint8_t MAC_McpsDataConfirm(MAC_McpsDataConfirm_t *McpsDataConfirm);
```

This “confirm” function checks for the result of the last data transmission request. The input object is a pointer to a MAC_Mcps_DataConfirm_t data structure consisting of the following fields:

- uint8_t ErrorCode
  Error code of the MCPS-DATA.confirm operation – this field is never used in the current firmware version.
- uint8_t MsduHandle
  The handle specified in the MCPS-DATA.request.
- uint8_t Status
  Status of the data transfer operation.
- uint32_t Timestamp
  Time at which the data transfer has been completed. Note: this is the device internal time which counts the time in milliseconds following power-on.

Return values:

- MAC_SAP_ERR_NO_ERROR – confirm event retrieved successfully;
- MAC_SAP_ERR_PREVIOUS_REQUEST – no confirm event retrieved yet.

The “status” field may be set to one of the following:

- MAC_SUCCESS – operation completed successfully;
- MAC_INVALID_ADDRESS – both destination and source addresses are missing;
- MAC_INVALID_QOS – a wrong value for QoS is requested (only 0/1 are valid);
- MAC_ADD_EVENT_ERROR – unable to transmit the packet because the transmitting machine is busy;
- MAC_CHANNEL_ACCESS_FAILURE – unable to transmit because the channel is busy;
- MAC_NO_ACK – Ack (when requested) is not received.

4.2.3 MCPS-DATA.indication

```
uint8_t MAC_McpsDataIndication(MAC_McpsDataIndication_t
*McpsDataIndication);
```

This primitive is issued in case of data reception.

Ack packets (when requested) are handled internally by the MAC routines. The application level receives confirmation of proper handling when an “indication” is signaled.

The “indication” signaling is also associated with a positive result from any frame corruption (reserved fields/wrong values) check.

Explanation of MAC_McpsDataIndication_t data structure:

- uint8_t ErrorCode
  The error code related to the reception event. Always set to the value MAC_SAP_ERR_NO_ERROR.
- MAC_DeviceAddress_t SrcAddr
  The source address.
- MAC_DeviceAddress_t DstAddr
  The destination address. Note that this address has already been checked, so this “indication” signal means the packet is in the correct desired destination node.
- uint16_t MSDULen
  Length in bytes of the packet.
- uint8_t MSDU[NEXT_HIGHER_LAYER_MAX_PDU_LENGTH]
  The actual MSDU.

uint8_t msduLinkQuality
SNR value detected during reception of this packet. In case of segmented reception, this value derives from the latest received segment.

- uint8_t DSN
  Data Sequence Number. The sequence number identification of a single transmission.
- uint32_t TimeStamp
  Time of completion of the reception operation.
- uint8_t SecurityLevel
  Information about security setting (cryptography) of the frame. Not used in the current version of the firmware.
- uint8_t QoS
  Requested quality of service set by the sender (0: normal quality, 1: high quality).

Return values:

- MAC_SAP_ERR_NO_ERROR – the function returned a valid “indication” event;
- MAC_SAP_ERR_NOINDICATION_PRESENT – no “indication” present, that is, no packet received at the moment.

4.3 Management services

The following services involve the MLME (MAC subLayer Management Entity) and all the internal MAC management.

4.3.1 MLME-BEACON-NOTIFY.indication

```
uint8_t MAC_MlmeBeaconNotify(MAC_MlmeBeaconNotify_t *MlmeBeaconNotify);
```

This primitive is issued when a node receives a beacon. The fields of the MAC_MlmeBeaconNotify_t data structure are set as follows:

- uint8_t ErrorCode
  The error code returned by the reception operation.
- MAC_PanDescriptor_t PanDescriptor
  The data structure filled with data from the sender coordinator node.

The return values:

- MAC_SAP_ERR_NO_ERROR – a valid “indication” was retrieved;
- MAC_SAP_ERR_NOINDICATION_PRESENT – no “indication” event is present.

The ErrorCode field is always set with value MAC_SAP_ERR_NO_ERROR.

The MAC_PanDescriptor_t structure has the following fields:

- MAC_DeviceAddress_t CoordAddress
  Address of the sender coordinator.
- uint16_t SuperFrameSpec
  The two-byte SuperFrameSpecification received as payload of the beacon.
- uint8_t GTSPermit
  Permission for GTS (guaranteed time slot). Not used in this protocol version; it is always zero.
- uint8_t LinkQuality
  Signal quality at reception of the beacon, that is, the SNR detected during decoding.
- uint32_t Timestamp
  Arrival time of the beacon.
- uint8_t SecurityFailure
  This field signals problems during decryption of the frame. Not used in this protocol version, always set to MAC_SUCCESS.
- uint8_t SecurityLevel
  Cryptographic protection level of the Beacon frame. Not used in this protocol version.

4.3.2 MLME-GET.request

```
uint8_t MAC_MlmeGetReq(MAC_MlmeGetReq_t *MlmeGetReq);
```

This primitive requests a “get” (read) operation on the MAC internal database, PIB (PAN Information Base), providing the object that the function must read.

Fields of the MAC_MlmeGetReq structure:

- uint32_t PIBAttribute
  Integer ID of the attribute to read. See Appendix 3 for Attribute list.
- uint8_t PIBAttributeIndex
  Index used in case of list-attribute.

Return values:

- MAC_SAP_ERR_NO_ERROR – the primitive was issued with no errors;
- MAC_SAP_QUEUE_ERRFULL – unable to issue the event to the FSM.

The only list attribute managed by the MAC is the neighbor table, which contains information about any known node of the network. Its ID is MAC_NEIGHBORTABLE_ID.

4.3.3 MLME-GET.confirm

```
uint8_t MAC_MlmeGetConfirm(MAC_MlmeGetConfirm_t *MlmeGetConfirm);
```

This function checks whether a “confirm” event has been issued following a previous GET.request and returns the attribute value.

Explanation of the MAC_MlmeGetConfirm data structure:

- uint8_t ErrorCode
  Result of the operation, always MAC_SAP_ERR_NO_ERROR.
- uint8_t State
  State flag of the GET operation; it may have one of the following values: MAC_SUCCESS for a successful read, MAC_UNSUPPORTED_ATTRIBUTE when the requested attribute is not found or MAC_INVALID_INDEX when a list attribute is specified but the wrong index is provided.
- uint32_t PIBAttribute
  ID of the attribute
- uint8_t PIBAttributeIndex
  Attribute index for a GET operation on a list attribute.
- uint8_t PIBAttributeValue[SAP_MAX_ATTRIBUTEVALUEGET_LEN]
  The value retrieved by the GET operation. The buffer is SAP_MAX_ATTRIBUTEVALUEGET_LEN bytes long (default 20), although 13 are used at most.
- uint8_t PIBAttributeValueLen
  Length in bytes of the attribute.

Return values:

- MAC_SAP_ERR_NO_ERROR – a valid “confirm” event was copied into the MAC_MlmeGetConfirm data structure;
- MAC_SAP_ERR_PREVIOUS_REQUEST – no “confirm” event was found.

Note: The PIBAttributeValue buffer has different contents depending on the actual attribute. For a read from the Neighbor Table, it is structured as a small set of integer values related to a specified node, in the following sequence:

- 2 bytes for the actual PAN ID;
- 2 bytes for the actual short address (optional);
- 8 bytes for the extended address (optional);
- 1 byte for the age of the entry (in minutes).

This structure is therefore 5 bytes long (when only the short address is present) or 11 bytes long (when only the extended address is present) or 13 bytes long (when both short and extended address are present). In order to distinguish between these cases, refer to the PIBAttributeValueLen value beforehand.

For integer values, the structure is simpler (1, 2, 4 bytes).

When reading the extended address of the current node, the PIBAttributeValue is set with a pointer (32-bit value) to an 8-byte buffer with the long address.

4.3.4 MLME-SET.request

```
uint8_t MAC_MlmeSetReq(MAC_MlmeSetReq_t *MlmeSetReq);
```

This function is called when a SET.request must be issued. The parameter contains the attribute identifier and its new value. The MAC_MlmeSetReq_t data structure fields are:

- uint32_t PIBAttribute
  The integer identifier of the attribute to be set. See Appendix 3 for Attribute list.
- uint8_t PIBAttributeIndex
  The index for a list attribute.
- union PIBAttributeValue
  This field has one of the following values: value8 (unsigned 8-bit value), value16 (unsigned 16-bit value), value32 (unsigned 32-bit value), buffer (a generic buffer – its length is SAP_MAX_ATTRIBUTEVALUESET_LEN bytes, defaulted to 4).
- uint8_t PIBAttributeValueLen
  Length in bytes of the value stored in the PIBAttributeValue field.

Return values:

- MAC_SAP_ERR_NO_ERROR – the “request” primitive has been successfully issued to the MAC;
- MAC_SAP_QUEUE_ERRFULL – the FSM has no further room for a new SET.request event.

4.3.5 MLME-SET.confirm

```
uint8_t MAC_MlmeSetConfirm(MAC_MlmeSetConfirm_t *MlmeSetConfirm);
```

This function checks for a SET confirm event. The MAC_MlmeSetConfirm_t data structure has the following fields:

- uint8_t ErrorCode
  The error code returned from the “confirm” primitive; it is always MAC_SAP_ERR_NO_ERROR.
- uint8_t State
  The state of the SET operation. It may have one of the following values: MAC_SUCCESS (when there are no errors), MAC_UNSUPPORTED_ATTRIBUTE (when the attribute is not found), MAC_READ_ONLY (the requested attribute is read-only).
- uint32_t PIBAttribute
  The 32 bit identifier of the specified attribute.
- uint8_t PIBAttributeIndex
  The index for a list attribute.

Return values:

- MAC_SAP_ERR_NO_ERROR – the function call returns a valid “confirm” event;
- MAC_SAP_ERR_PREVIOUS_REQUEST – no “confirm” event was found.

4.3.6 MLME-RESET.request

```
uint8_t MAC_MlmeResetReq(MAC_MlmeResetReq_t *MlmeResetReq);
```

This function requests a reset of the MAC layer. The MAC_MlmeResetReq_t data structure has a single field:

- uint8_t SetDefaultPIB
  This flag tells the engine whether or not to reset the PIB during the software reset. Set it to 1 to reset or 0 to leave it with latest values.

The reset operation always involves a hardware reset of the ST7580 modem. The PANDescriptorList and the neighbor table structures are also cleaned.

Return values:

- MAC_SAP_ERR_NO_ERROR – the request was successfully issued;
- MAC_SAP_ERR_IMPLEMENTATION – the Reset FSM was unable to accept a new request.

4.3.7 MLME-RESET.confirm

```
uint8_t MAC_MlmeResetConfirm(MAC_MlmeResetConfirm_t *MlmeResetConfirm);
```

This function checks for a "confirm" for a previous RESET.request primitive. The MAC_MlmeResetConfirm_t data structure has the following fields:

- uint8_t ErrorCode
  Result of the "confirm" event; it is always set to MAC_SAP_ERR_NO_ERROR.
- uint8_t Status
  Status of the reset operation; it always has the value MAC_SUCCESS.

Return values:

- MAC_SAP_ERR_NO_ERROR – the "confirm" event was retrieved successfully;
- MAC_SAP_ERR_PREVIOUS_REQUEST – no "confirm" event.

4.3.8 MLME-SCAN.request

```
uint8_t MAC_MlmeScanReq(MAC_MlmeScanReq_t *MlmeScanReq);
```

When a node starts up, the next layer above MAC calls the active scan procedure in order to check the actual network status. This function issues the necessary primitive and other nodes, if any, send their beacons. See *Appendix A* for the complete description of the join procedure. The parameters in the MAC_MlmeScanReq_t are:

- uint8_t ScanType
  Select the scan type. Only Active Scan is allowed; set this to the value MAC_ACTIVE_SCAN.
- uint32_t ScanChannels
  Used for selecting channels to check during the scan operation. Not used in this protocol version.
- uint8_t ScanDuration
  Duration in seconds for the whole scan operation (max. is 60, a zero setting is not allowed).
- uint8_t ChannelPage
- uint8_t SecurityLevel
  These parameters are not used in this version of the software.

Return values:

- MAC_SAP_ERR_NO_ERROR – the "request" event was successfully issued to the Scan FSM;
- MAC_SAP_ERR_IMPLEMENTATION – unable to send the request to the scan FSM.

4.3.9 MLME-SCAN.confirm

```
uint8_t MAC_MlmeScanConfirm(MAC_MlmeScanConfirm_t *MlmeScanConfirm);
```

This function checks for a “confirm” event after a previous scan request. The MAC_MlmeScanConfirm_t data structure has the following fields:

- MAC_PanDescriptorList_t PanDescriptorList
  This structure consists of an unsigned byte, PanDescriptorCount, which counts how many Beacon frames have been received, and an array of MAC_PanDescriptor_t PanDescriptor; these have the structure shown in *Chapter 4.3.1*.
- uint8_t ErrorCode
  Error code of the “confirm” event; it is always set to MAC_SAP_ERR_NO_ERROR.
- uint8_t Status
  Status of the Scan operation; it may have one of the following values: MAC_SUCCESS (successfully completed), MAC_SCAN_IN_PROGRESS (another Scan sequence was already pending), MAC_INVALID_PARAMETER (a wrong Scan value was specified for the scan type and/or duration), MAC_ADD_EVENT_ERROR (unable to transmit the Beacon Request Command frame), or any of the error codes returned by the transmission FSM (listed in *Chapter 4.2.2*).
- uint8_t ScanType
  Always set to MAC_ACTIVE_SCAN.

Return values:

- MAC_SAP_ERR_NO_ERROR – the “confirm” data was successfully retrieved;
- MAC_SAP_ERR_PREVIOUS_REQUEST – no “confirm” event available.

4.3.10 MLME-START.request

```
uint8_t MAC_MlmeStartReq(MAC_MlmeStartReq_t *MlmeStartReq);
```

With this function, a node can set the PAN ID and its role in the network (coordinator/PAN coordinator). The parameters are found in the MAC_MlmeStartReq_t structure:

- uint8_t CoordRole
  This flag controls whether the node is a PAN Coordinator (set this field to DEVICE_TYPE_PAN_COORDINATOR) or a Coordinator (set this field to DEVICE_TYPE_COORDINATOR)
- uint16_t PanId
  The 16 bit PAN identifier. Note that, although the application may choose this identifier randomly, the protocol requires that it is logically and-ed with 0xFCFF.

Return value:

- MAC_SAP_ERR_NO_ERROR – the request was issued to the MAC.

4.3.11 MLME-START.confirm

```
uint8_t MAC_MlmeStartConfirm(MAC_MlmeStartConfirm_t *MlmeStartConfirm);
```

When called, this function checks for a “confirm” event relative to a previous start request.

The results are stored into the MAC_MlmeStartConfirm_t structure:

- uint8_t ErrorCode
  Error code from the “confirm” retrieval operation; it is always set to MAC_SAP_ERR_NO_ERROR.
- uint8_t Status
  Status code of the Start operation; it may have the values MAC_SAP_ERR_NO_ERROR (Start sequence completed successfully) or MAC_INVALID_PARAMETER (the specified PAN ID is invalid).

Return values:

- MAC_SAP_ERR_NO_ERROR – a valid “confirm” event is present;
- MAC_SAP_ERR_PREVIOUS_REQUEST – no “request” was previously issued.

4.3.12 MLME-COMM-STATUS.indication

```
uint8_t MAC_MlmeCommStatusIndication(MAC_MlmeCommStatusIndication_t
*MlmeCommStatusIndication);
```

This function checks for a communication status “indication” event from the MAC, that is, a detailed report about the last communication event. The MAC_MlmeCommStatusIndication_t data structure has the following fields:

- uint8_t ErrorCode
  The error code of the “confirm” event check; it is always set to MAC_SAP_ERR_NO_ERROR.
- uint16_t PanId
  This is the PAN identifier of the source node.
- MAC_DeviceAddress_t SrcAddr
- MAC_DeviceAddress_t DstAddr
  The addresses of both source and destination nodes.
- uint8_t Status
  Last result of the communication channel. May be one of the following values: MAC_COUNTER_ERROR (problem during reassembly process due to wrong segment received), MAC_NO_ACK (after transmission, an ack was expected but never received), MAC_CHANNEL_ACCESS_FAILURE (the medium was detected as busy too many times, transmission aborted).
- uint8_t SecurityLevel
  Code related to cryptography of the message. Not used in this version of the software.

Return values:

- MAC_SAP_ERR_NO_ERROR – an “indication” event was successfully retrieved.
- MAC_SAP_ERR_NOINDICATION_PRESENT – no “indication” was found.

4.3.13 MLME-SYNC-LOSS.indication

```
uint8_t MAC_MlmeSyncLossIndication(MAC_MlmeSyncLossIndication_t
*MlmeSyncLossIndication);
```

This primitive is issued to the next layer above when an overlapping PAN is detected – this case is called PAN ID conflict. The structure of the MAC_MlmeSyncLossIndication_t block is as follows:

- uint8_t ErrorCode
  Error code related to the "indication" event; it is always set to MAC_SAP_ERR_NO_ERROR.
- uint8_t LossReason
- uint16_t PanId
  The new discovered PAN identifier.

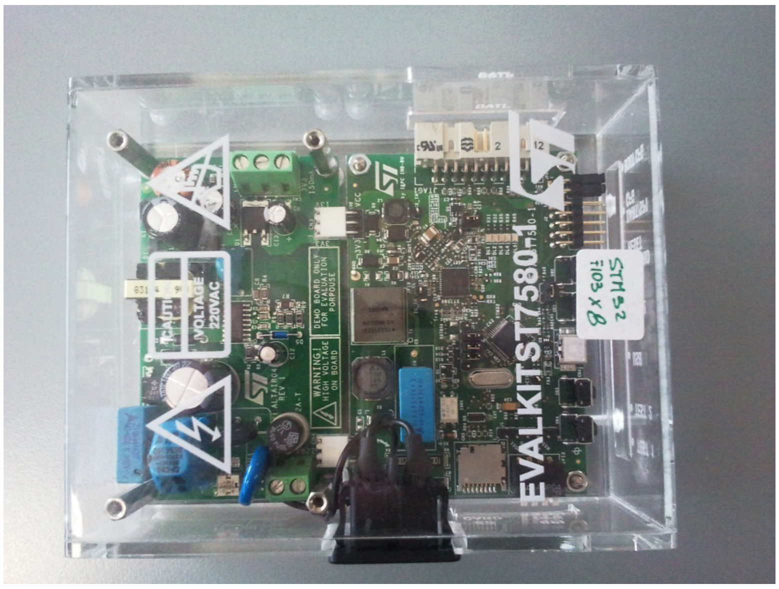
Return values:

- MAC_SAP_ERR_NO_ERROR – an "indication" event was successfully retrieved.
- MAC_SAP_ERR_NOINDICATION_PRESENT – no "indication" event found.

5 Application example

The protocol library is delivered with a simple application example running on the EVALKITST7580-1, shown in the following picture.

Figure 4. EVALKITST7580-1



The application simulates a simple data collection operation from “sensor” nodes to a data concentrator, and a command transmission operation from the data concentrator to the “sensor” nodes.

It functions along the following description, using at least two kits for communication evaluation:

Following boot, the board starts the active scan procedure for 10 seconds and, if no beacon are received (because it is alone or it is the first to be powered up), it elects itself as PAN coordinator and starts the MAC as PAN coordinator. During scan procedure the LEDs DL3 and DL5 blink.

If a beacon is received because a PAN coordinator already exists, the board starts the MAC as a normal coordinator with the retrieved PAN_ID and a random local short address.

After the association process finishes, the normal coordinator sends dummy messages to the PAN coordinator periodically. During normal operation of the coordinator, the LED DL5 blinks.

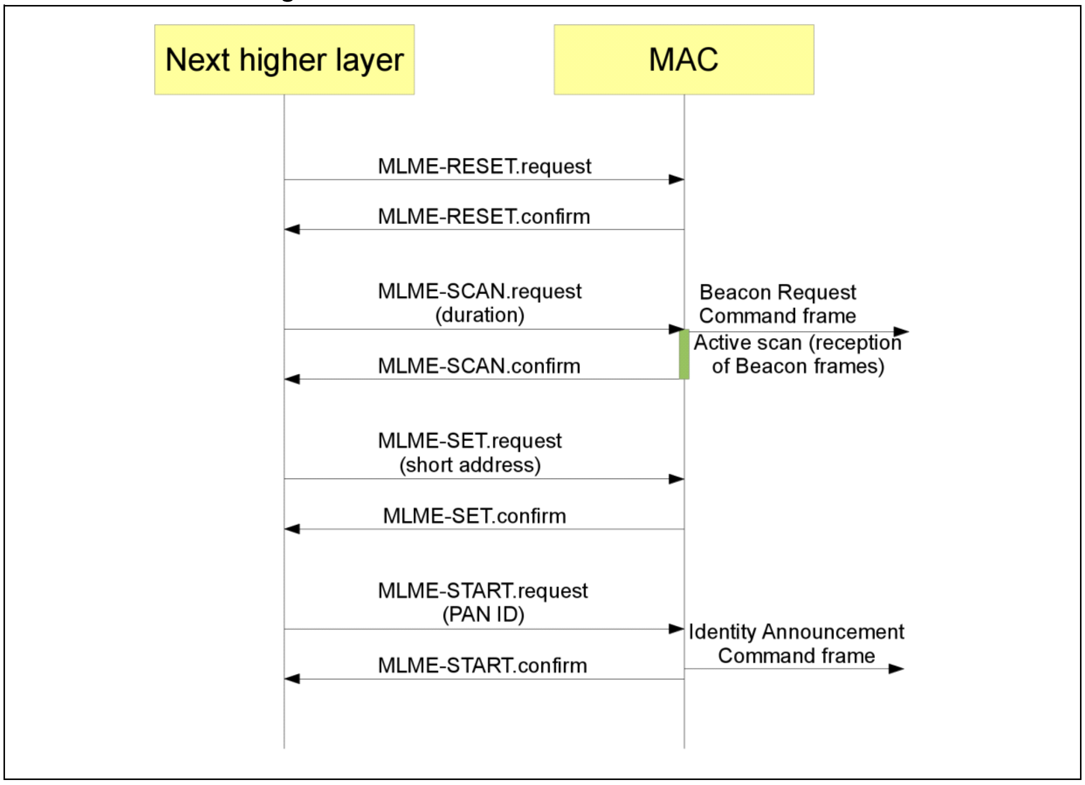
The PAN coordinator maintains a table of 3 nodes from the MAC neighbor table associated with LEDs DL3, DL4 and DL5 of the board; each time it receives a message from one normal coordinator, it toggles the associated LED. If the TEST 1 button of the PAN coordinator board is pushed, a broadcast command message is sent; as soon as the coordinator boards receive the command, they toggle the LED DL4.

For correct operation, a main super loop must call the MAC_FSMHandler function to run all the MAC finite state machines and the MODEM_FSM_Management function to run the STM32-ST7580 local communication finite state machine.

Appendix A Boot and join sequence

Figure 5 shows the boot of a new node and the association procedure. This includes the actual scan of the network, called “active scan”.

Figure 5. Boot and association of a new node


Next higher layer
MAC
MLME-RESET.request
MLME-RESET.confirm
MLME-SCAN.request (duration)
Beacon Request Command frame
Active scan (reception of Beacon frames)
MLME-SCAN.confirm
MLME-SET.request (short address)
MLME-SET.confirm
MLME-START.request (PAN ID)
Identity Announcement Command frame
MLME-START.confirm

The actions performed by the node are:

- MLME-RESET: hardware and software reset of the device (modem and MAC)
- MLME-SCAN: scan of the network nodes (if any) through the beacon request command frame. Note that the duration is set by the caller.
- reception of beacon frames sent by other nodes.
- MLME-SET: setting of the attribute MAC_SHORTADDRESS_ID (also known as the short address of the device) and the node activity between the PAN coordinator and coordinator. Note that for the node to be a PAN Coordinator, the short address must be set to 0 (zero).
- MLME-START: start of the node transmissions. In this step, the node sets the PAN identifier and sends the identity announcement command frame with its own parameters such as associated PAN, short address and extended address.

Appendix B Modem setup

The main program can customize the modem configuration in order to set frequencies, reception mode, modulation scheme and the like.

```
void DL_LoadStartupConfig(DL_OBJ_T *DataLink, uint32_t freqH, uint32_t
freqL, uint8_t mod, uint8_t channel_config);
```

This function reads the default settings of the modem, copies them into the DataLink data structure and then customizes those values with the new ones provided by the caller. They are:

- uint32_t freqH
  The high reception frequency for the modem
- uint32_t freqL
  The low reception frequency for the modem.
- uint8_t mod
  Modulation scheme selection; this can be set to one of the following values: MODEM_MOD_BPSK, MODEM_MOD_QPSK, MODEM_MOD_8PSK, MODEM_MOD_BPSK_CODED, MODEM_MOD_QPSK_CODED, MODEM_MOD_BPSK_CODED_PNA.
- uint8_t channel_config
  Select between single channel reception (using either high or low frequency) and dual channel reception. This can be set to MODEM_PHY_CONFIG_RXMODE_DUAL for reception from both channels, MODEM_PHY_CONFIG_RXHIGH_PSK or MODEM_PHY_CONFIG_RXLOW_PSK for receiving frames from a high frequency channel or from a low frequency channel.

Appendix C PIB attributes

The application is able to read and modify MAC internal attributes in order to change software behavior or access other data. *Table 5* shows these attributes.

Table 5. List of PIB attributes

Identifier	R/W	Length	Default value
MAC_ACKWAITDURATION_ID (unit is 100 ms)	R/W	1	10
MAC_ASSOCIATEDPANCOORD_ID	R	1	0
MAC_ASSOCIATIONPERMIT_ID	R	1	1
MAC_MAXBE_ID	R	1	5
MAC_MAXCSMABACKOFFS_ID	R	1	8
MAC_MINBE_ID	R	1	3
MAC_RESPONSEWAITTIME_ID	R	1	30
MAC_SECURITYENABLED_ID	R	1	0
MAC_SHORTADDRESS_ID	R/W	2	0xFFFF
MAC_TIMESTAMPSUPP_ID	R	1	1
MAC_HIGHPRIORITYWS_ID	R	1	0
MAC_TXDATAPACKETCOUNT_ID	R/W	4	0
MAC_RXDATAPACKETCOUNT_ID	R/W	4	0
MAC_TXCMDPACKETCOUNT_ID	R/W	4	0
MAC_RXCMDPACKETCOUNT_ID	R/W	4	0
MAC_CSMAFAILCOUNT_ID	R	4	0
MAC_CSMACOLLCOUNT_ID	R	4	0
MAC_BROADCASTCOUNT_ID	R/W	4	0
MAC_MULTICASTCOUNT_ID	R/W	4	0
MAC_BADCRCCOUNT_ID	R	4	0
MAC_MAXORPHANTIMER_ID	R	4	0
MAC_NEIGHBORTABLE_ID	R	1	N/A
MAC_PANID_ID	R/W	2	0xFFFF
MAC_NUMBEROFHOPS_ID	R	1	0
MAC_FREQNOTCHING_ID	R/W	1	0
MAC_BSN_ID	R	1	0
MAC_DSN_ID	R	1	0
MAC_COORDINATORTYPE_ID	R/W	1	1
MAC_PROMISCUOUS_MODE	R/W	1	0
MAC_MAXFRAMERETRIES_ID	R/W	1	3

Table 5. List of PIB attributes (continued)

Identifier	R/W	Length	Default value
MAC_LASTPACKETLENGTH	R/W	1	48
MAC_EXTENDEDADDRESS_ID (pointer)	R	4	N/A

6 References

- ST7580: datasheet
- UM0932: user manual
- STM32F103 datasheet
- STM32F103 reference manual
- EVALKITST7580-1 data brief
- AN4068

7 Revision history

Table 6. Document revision history

Date	Revision	Changes
04-Jun-2014	1	Initial release.